Texture, Vol. 2
1975, pp. 1-15

TEXTURE CONTROL AND THE DRAWABILITY OF α-BRASS

J. R. RELLICK
Photo Products Dept., E.I. duPont de Nemours & Co., Wilmington, Delaware

and

A. LAWLEY
Department of Materials Engineering, Drexel University, Philadelphia, Pennsylvania 19104

(Received February 25, 1975)

Abstract: Texture strengthening analyses for cubic metals predict enhanced deep drawing performance with {110} and/or {111} components in the plane of the sheet. Since {110}<112> is the primary texture in heavily cold rolled α-brass, an attempt was made to retain this texture through recovery of the cold rolled material at low temperatures. A second approach is suggested by the observation of the {110} texture in α-brass on annealing $\gtrsim$600°C (873°K), and involves short time exposures to limit grain size. It is found that low temperature recovery treatments, while partially retaining the rolling texture, produce a hard condition of low drawability. High temperature annealing produces appreciable {110} textural components only at grain sizes too large for many commercial applications. A potentially more tractable approach is discussed.

INTRODUCTION

It is now generally accepted that the drawability of sheet material depends in part on the crystallographic texture present. Specific crystallographic orientations can give rise to improvements in drawing and pressing performance. The phenomenon of 'texture strengthening' may be defined as an increased resistance to yielding under various conditions of loading that may be caused by crystallographic texture.[1,2] Detailed reviews of the relationships between preferred orientation, plastic anisotropy and drawability in practice are available.[1-6]

Analytically, in cubic materials, $\{111\}$ and/or $\{110\}$ textural components in the plane of the sheet enhance drawability[1]; these textures strengthen the sheet in the through-thickness direction and increase resistance to fracture in the cup wall in deep-drawing. Of equal importance is the detrimental effect of a $\{100\}$ texture on through-thickness strength.

Of the non-ferrous metals, α-brass exhibits perhaps the best overall formability. This notwithstanding, small improvements are attractive to the sheet producer and fabricator *vis-à-vis* product range. Unfortunately, the recrystallization textures in α-brass are neither intense nor are they expected to be conducive to enhanced drawability via texture strengthening. The primary cold-rolled texture is of the type $\{110\}\langle 112\rangle$[7-12] and this changes to textures of the form $\{113\}\langle 112\rangle$[7], $\{225\}\langle 73\bar{4}\rangle$[9-11] or $\{326\}\langle 63\bar{4}\rangle$[13] on recrystallization at temperature below $\sim$500°C (773°K).

In the course of an extensive study of the interplay of material properties, anisotropy and processing parameters on the formability of α-brass[14], two approaches to texture-strengthening were identified as being possible alternatives to the above limitations. The first is based on the concept of annealing the cold-rolled material at low temperatures (i.e. recovery) in order to recover sufficient ductility for drawing but without allowing recrystallization to take place. Such a treatment could result in the retention of the primary $\{110\}\langle 112\rangle$ cold-rolled texture, a texture expected to enhance drawability.[1] Similarly, it is known that $\{111\}\langle uvw\rangle$, a further desirable component, exists as a secondary texture in cold-rolled α-brass.[12] An alternate approach is suggested by the observation of a $\{110\}$ texture in α-brass following annealing at temperatures in the range 600°C to 800°C (873°K to 1073°K).[5,11] If this texture which is favorable in terms of drawability is an intrinsic effect of the high annealing temperature, rather than the result of grain growth, then the potential exists for producing material with the required $\{110\}$ textural component. To maintain a grain size compatible with commercial applications, exposure times in the high-temperature range must be short. These two approaches of long-time low temperature recovery and short-time high-temperature recrystallization were evaluated in α-brass with respect to drawability.

EXPERIMENTAL PROCEDURES

Materials and Specimen Preparation

Commercial 70/30 brass was obtained from Olin Metals Division in the form of 0.425 inch (10.8 mm) hot rolled plate. The brass was rolled at ambient temperature to a final thickness of between 0.030 inch (0.762 mm) and 0.032 inch (0.813 mm) giving a cold reduction from 92% to 93%. The strip was not reversed end-to-end between passes.

Circular blanks for deep drawing were cut, de-burred and annealed along with rectangular samples for x-ray pole figure analysis, hardness measurement, and metallography. Two series of heat-treatments were performed. Low-temperature long-time anneals were of a 20 hour (7.2×10^4 s) duration at increments of 50 degrees between 250°C (523°K) and 450°C (723°K). High-temperature short-time annealing was carried out at a temperature of 750°C (1023°K) for times in the range 10 s to 3600 s; for this purpose it was necessary to use a salt bath with a proprietary non-corrosive medium.* Following heat treatment, all specimens were pickled in an aqueous solution of 40% nitric acid.

Pole Figures

Quantitative pole figures were generated by the Schulz single sample reflection method[15] for planes lying within 75° (1.039 rad) of the plane of the sheet. CuK_α radiation was used with the specimen mounted in a Siemens three circle goniometer moving at tilt and spin angular velocities of 1° per minute (2.9×10^{-4} rad.s^{-1}) and 72° per minute (2.09×10^{-2} rad.s^{-1}) respectively. Intensity data were transferred to the corresponding spiral path on a stereographic projection. The unit of intensity used in plotting pole figures was that derived from a random sample prepared from brass filings.

Drawability

Swift cupping tests were performed on a Tinius Olsen Ductomatic testing machine in strict accordance with established IDDRG procedures.[16] Punch and die diameters were 1.259 inches (31.979 mm) and 1.354 inches (34.392 mm) respectively which gave a clearance of ∿60% for the 0.030 inch (0.762 mm) sheet during drawing. The lubricant was TSD-996 (Humble Oil, Ltd.) with a hold down

---

* 'Liquid Heat 300' - E. F. Houghton and Company.

pressure of 1000 lb. (4550N) at a drawing speed of 1 inch per minute (0.423 mm.s^{-1}). To conserve material, drawability was assessed by means of a modified "single-blank" test.[17-20] Specimen blanks were drawn to the point of maximum load (indicated by a small but perceptible drop in punch force) at which time the punch travel was stopped, and the hold down pressure increased to 3000 lb. (13650N) to securely clamp the partially drawn blank in place; punch travel was then resumed until fracture of the cup side wall occurred. By repeating this procedure for a series of blank sizes, the limiting blank diameter could be determined as that diameter for which the maximum drawing load was equal to the load required for fracture of the drawn cup.

RESULTS

Low Temperature-Long Time Annealing

Microstructure and texture. Figure 1 shows the Rockwell B hardness of specimens initially cold-rolled

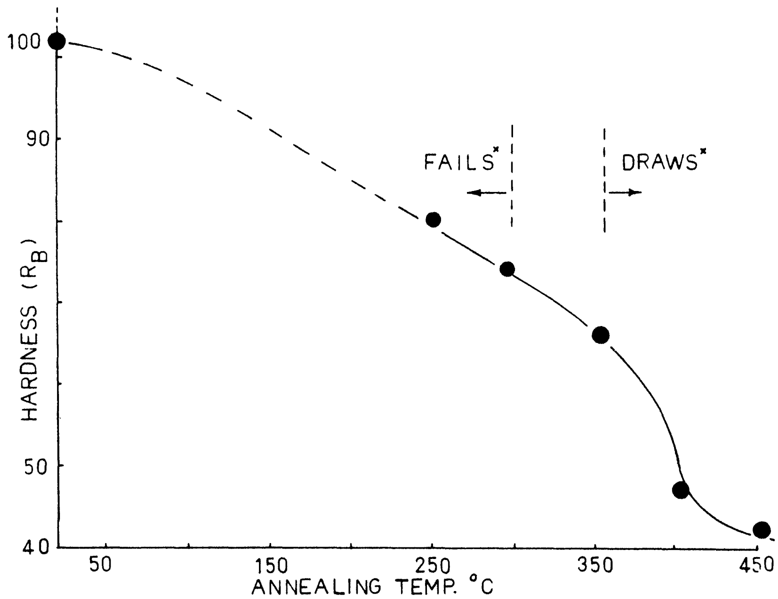
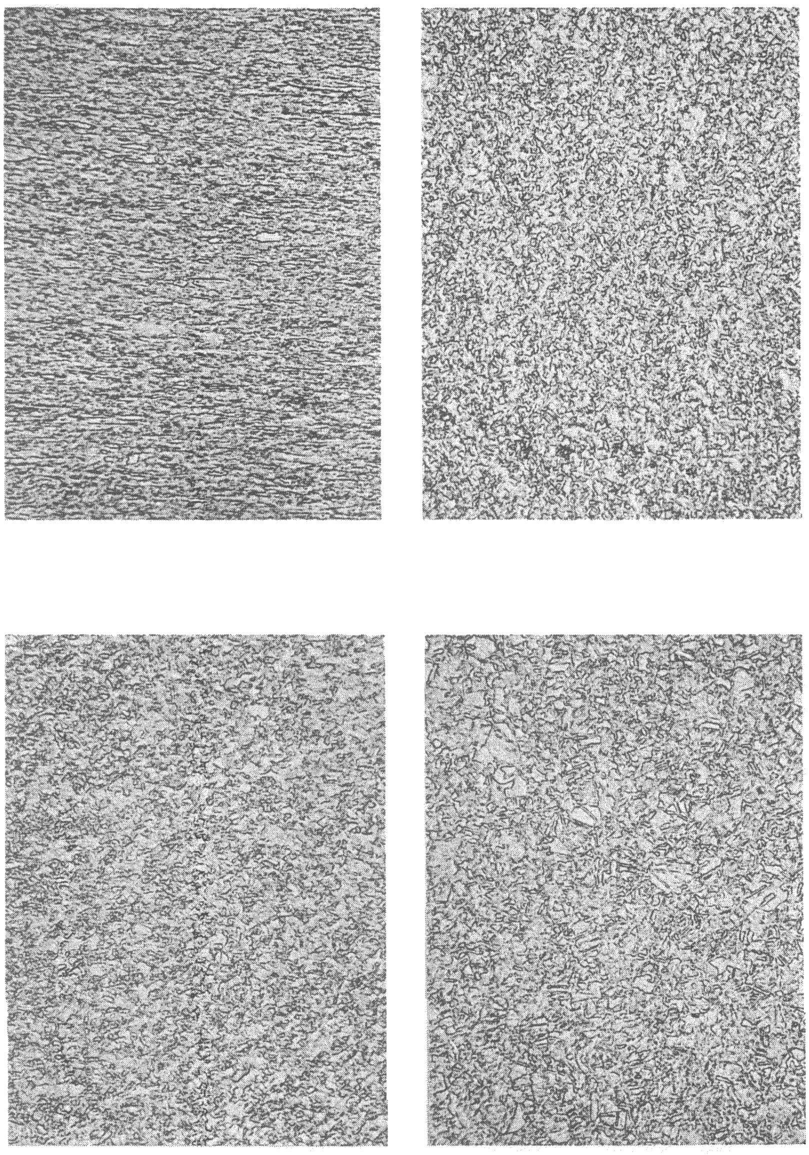
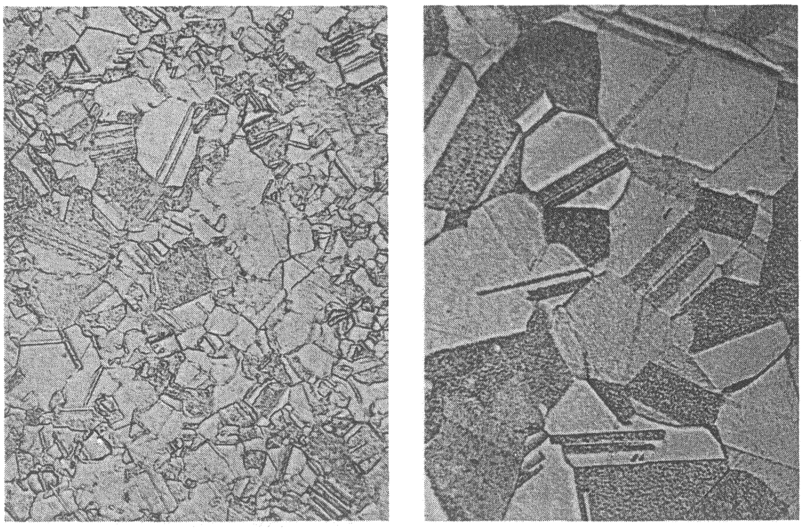


FIGURE 1. Hardness of α-brass sheet as a function of annealing temperature. Material annealed for approximately 20 hours (7.2 x 10^4 s) following a 92%-93% reduction by cold rolling. x refers to 2.76 inch (70 mm) diameter blank; °K = °C + 273.

92% to 93% reduction and annealed for 20 hours (7.2 x 10^4s) at the temperatures indicated. The corresponding microstructures are presented in Figure 2. It may be seen



(c) (d)

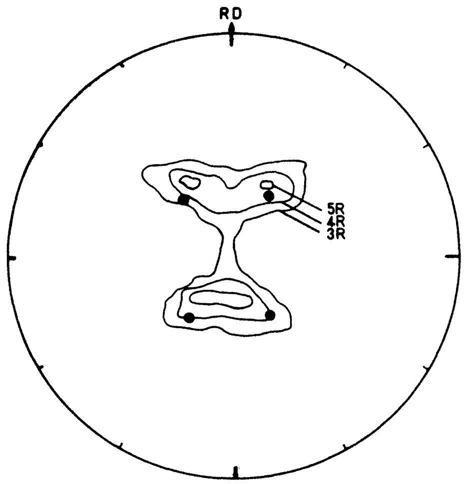


(e) (f)

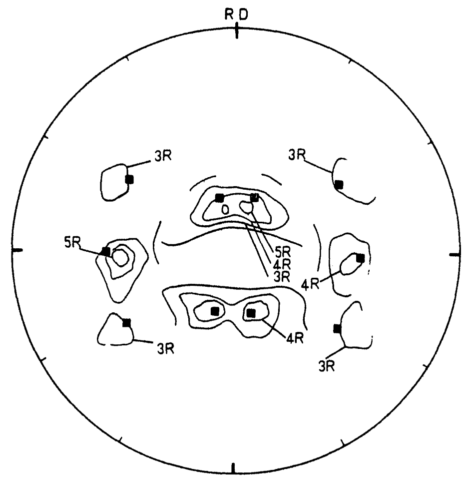
FIGURE 2. Optical microstructures of α-brass sheet cold-rolled 92%-93% and annealed at the temperatures and times indicated: (a) as-rolled; (b) 18 hr (6.48×10^4s) at 252°C (525°K); (c) 18.5 hr (6.66×10^4s) at 297°C (570°K); (d) 22 hr (7.92×10^4s) at 353°C (626°K); (e) 18 hr (6.48×10^4s) at 403°C (676°K); (f) 18.5 hr (6.66×10^4s) at 452°C (725°K); all magnifications 500X; all sections taken perpendicular to plane of sheet and to rolling direction.

that annealing at a temperature as low as 250°C (523°K) modifies the elongated grain structure resulting from cold rolling. After annealing at 300°C (573°K) and 350°C (623°K) the microstructure is composed of small recrystallized grains in a recovered matrix. The structure is fully recrystallized after annealing at 400°C (673°K).

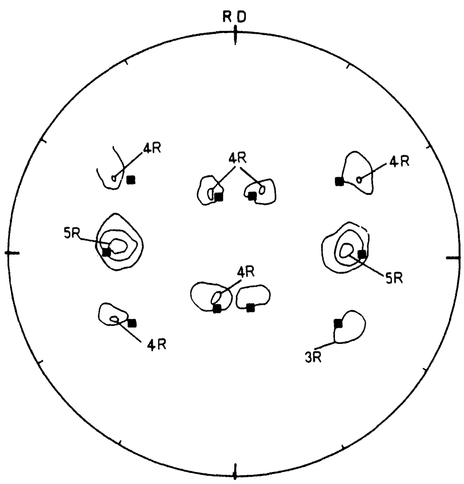
The pole figures provide a more quantitative assessment of the degree of recrystallization. {111} pole figures for the as-rolled condition and following annealing at 300°C (573°K) and 400°C (673°K) are illustrated in Figure 3. The texture of cold rolled sheet (Figure 3-a) is the characteristic {110}<112> "alloy" or brass-type texture at a level of about five times random intensity. Asymmetry about the transverse direction is attributed to the fact that the rolling schedule did not involve end-to-end reversals between passes. Hu *et al.*[8] previously observed asymmetry in the surface layers of heavily worked 70/30 brass rolled without end-to-end



(a)



(b)



(c)

FIGURE 3. {111} pole figures of α-brass; (a) rolled 92%-93%, (b) annealed at 297°C (570°F) for 18.5 hr (6.66 x 10^4s), (c) annealed at 403°C (676°K) for 18 hr (6.48 x 10^4s).

■ indicate pole positions for a {113}<112> texture.

● indicate pole positions for a {110}<112> texture.

reversals. The primary texture in sheet annealed for 20 hours (7.2×10^4s) at 300°C (573°K) Figure 3(b), and 400°C (673°K) Figure 3(c), is of the type {113}<112> or {225}<734>, i.e. the primary texture characteristic of recrystallized α-brass following a high level of cold work.[7,9-11] Thus, recrystallization is well-advanced at annealing temperatures as low as 300°C (573°K). This is consistent with the work of Horiuchi *et al.*[11] who report that while the rolling texture is retained for a short time at 300°C (573°K), {110}<112> is completely absent after annealing for a period of 14 hours (5×10^4s) at 300°C (573°K). The prospects for improving drawability by the route of long-time low-temperature recovery treatments to retain the worked texture in heavily rolled α-brass therefore appear limited.

Drawability. Drawability was measured by the single blank test described previously, using tooling for the Swift cup test. Fracture load and drawing load are plotted in Figure 4 as a function of blank diameter. The

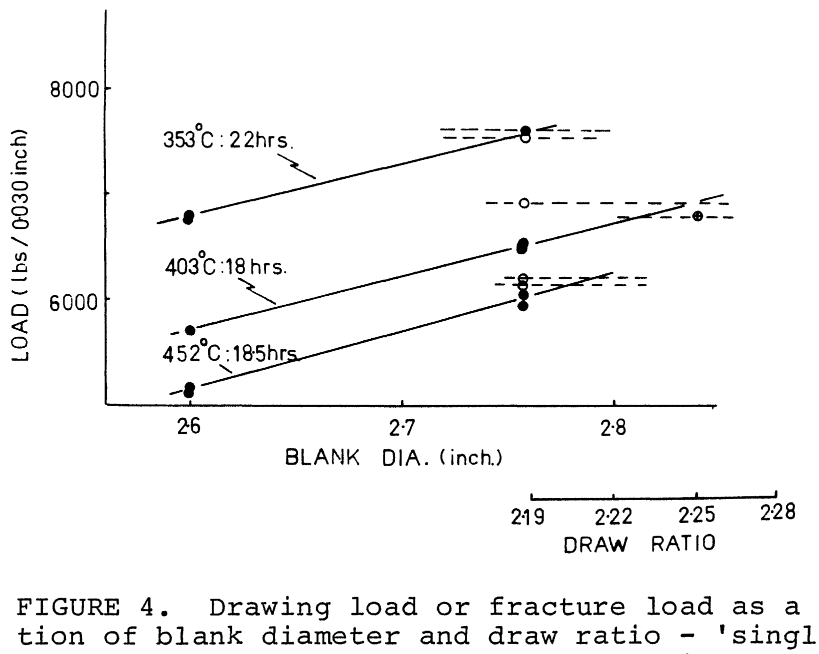


FIGURE 4. Drawing load or fracture load as a function of blank diameter and draw ratio - 'single-blank' draw tests on α-brass. ● ≡ maximum drawing load; O ≡ fracture load; ⊕ ≡ one draw, one fail. 1 inch = 25.4 mm; 1N = 0.22 lb (force); °K = °C + 273; 1 hr = 3.6×10^3s.

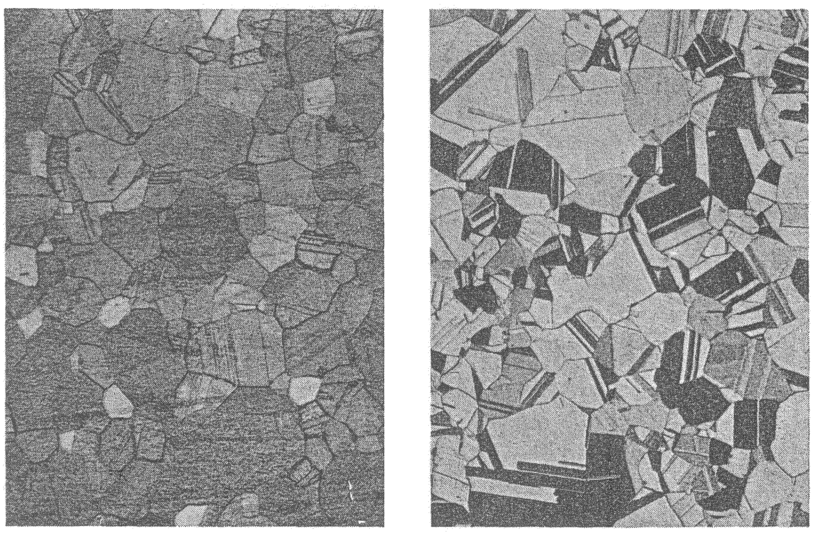
data refer to material annealed at the upper end of the temperature range examined, *cf.* Figure 1. The drawing load increases approximately linearly with increasing blank diameter while the fracture load (determined by interrupting the draw after the point of maximum punch load is reached and clamping the blank) remains nearly constant with changing blank diameter. The limiting blank diameter is that for which the drawing load just equals the fracture load. Fracture loads could be obtained only for blank sizes larger than ∿2.7 inches (68.58 mm) due to inability to effectively clamp smaller blanks with the tooling available. Also shown on the abscissa in Figure 4 is the draw ratio. By this method, a limiting draw ratio (LDR) can be established to within ±0.02; while less precise by a factor of two than the conventional 50% failure criterion with α-brass[14-21], the accuracy was sufficient to establish the relative drawabilities following annealing.

From Figure 4 it is seen that the highest draw ratio was associated with annealing at 403°C (676°K) for 18 hours (6.48×10^4s). This treatment gave a draw ratio of 2.24 which is essentially the level characteristic of α-brass following conventional processing at a similar grain size.[14] This is understandable since following annealing at this relatively high temperature, there is no significant contribution to drawability from a retained rolling texture. The drawability of material annealed at 250°C (523°K) and 300°C (573°K) was inferior to that of material annealed at the three highest temperatures.

In summary, these long-time low-temperature annealing studies show that in heavily cold rolled α-brass loss of the rolling texture {110}<112> due to recrystallization occurs at temperatures too low to allow for exploitation of the preferred working texture to improve drawability. Maximum drawability occurs in material which, while having a suitable grain size in the range 20 μm to 30 μm, possesses a primary texture of the form {113}<112>.

High Temperature-Short Time Annealing

Microstructure and texture. A representative microstructure of the α-brass annealed for the shortest time period, 10 s, at 750°C (1023°K) is shown in Figure 5. The corresponding {111} pole figure is given in Figure 6. Thus, this short-time anneal results in a fully recrystallized structure with the {113}<112> type texture. In addition {110}<112> is present as a secondary textural component.



(a) (b)

FIGURE 5. A comparison of microstructures after low and high temperature annealing. (a) annealed at 750°C (1023°K) for 10 s; 200X. (b) annealed at 452°C (725°K) for 18.5 hr (6.67 x 10^4s); 200X; *cf.* Figure 2(f) at 500X.

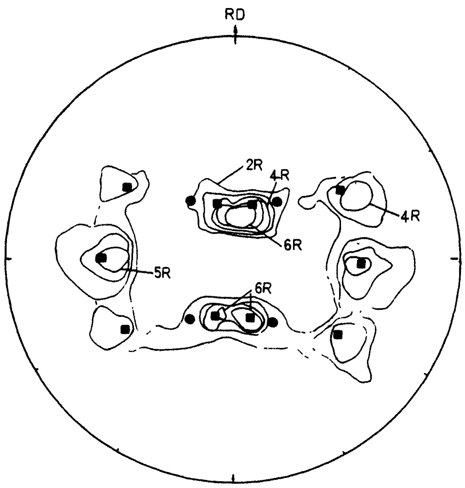


FIGURE 6. {111} pole figure of α-brass rolled 92%-93% and annealed at 750°C (1023°K) for 10 s.

■ indicates pole positions for {113}<211> texture.

● indicates pole positions for {110}<112> texture.

To assess the amount of {110} component present, {220} pole figures were generated and the average intensity of {220} poles lying within 10° (17.45×10^{-2} rad) of the plane of the sheet determined. This was done by integrating the intensity over this angular range with a scalar and comparing it to the integrated intensity of {220} planes from a random sample over the same 10° (17.45×10^{-2} rad) angular range. These data are presented in Table I for various annealing times at 750°C (1023°K) along with the resulting grain sizes determined

TABLE I

{220} Intensity level within 10° (17.45×10^{-2} rad) of the sheet plane normal

Annealing Time at 750°C (1023°K)	Times Random Intensity	Average Grain Size (μm)	Grain Size Range (μm)
10 s	1.557	40	25 - 50
30 s	2.049	75	50 - 100
120 s	2.110	125	75 - 175
600 s	2.264	300	90 - 450
3600 s	3.638	450	--
6.66×10^4 s at 452°C (725°K)	1.988	40	25 - 50

from photomicrographs. It can be seen that the {110} component of the texture is minor for the 10 s anneal, but increases appreciably at longer times, at which grain size is larger. Thus, it appears likely that the {110}<112> texture reported in α-brass following annealing at 750°C (1023°K)[5,11] is the result of grain growth rather than an intrinsic effect of temperature on recrystallization texture.

This conclusion is reinforced by a comparison of the microstructures due to a 10 s anneal at 750°C (1023°K) and that produced after 20 hours (7.2 x 10^4s) at 450°C (723°K). The pertinent micrographs [Figures 5(a) and 5(b) respectively] show that these two diverse annealing treatments produce a similar grain size. Further, data for the low-temperature, long-time anneal (included in Table I) show that the amount of the {110} texture is about the same for the two annealing treatments.

Drawability. The similarity of texture and grain size are also reflected in a comparison of drawability resulting from these two treatments. The comparison is made in Figure 7. There is virtually no difference in

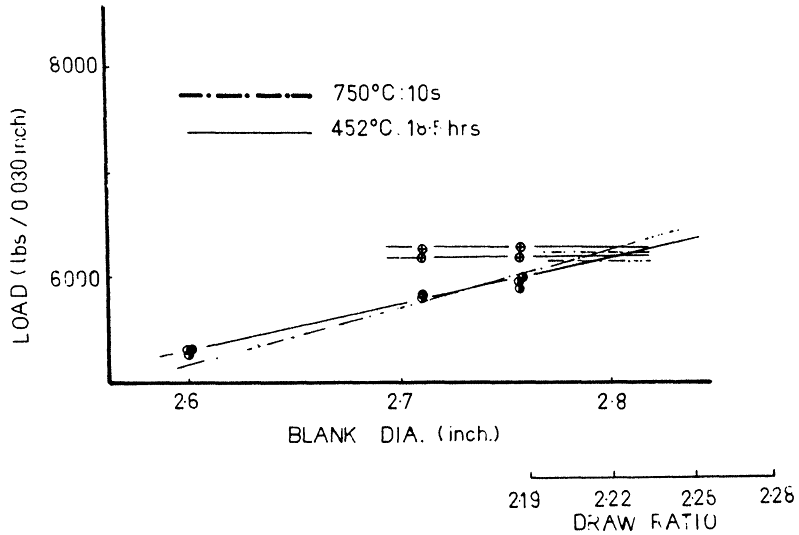


FIGURE 7. A comparison of the drawability of α-brass for annealing conditions of 452°C (725°K) for 18.5 hr (6.66 x 10^4s) and 750°C (1023°K) for 10 s; sheet originally cold rolled 92%-93% reduction. ◑ ≡ maximum drawing load; ⊕ ≡ fracture load for for short-time, high-temperature anneal; data points for long-time, low-temperature anneal on Figure 4; 1N = 0.22 lb (force).

the drawing response of the material annealed 10 s at 750°C (1023°K) compared to material annealed 20 hours (7.2 x 10^4s) at 450°C (723°K).

DISCUSSION

It is clear from the results of this study and from the work of Horiuchi *et al.*[11] that in heavily rolled 70/30 brass the rolling texture can only be retained by limiting the extent of annealing to less than 14 to 20 hours (5.04×10^4s to 7.2×10^4s) at 300°C (573°K) or equivalent times at other temperatures. There appears to be no previous data available on the drawability attainable with such low temperature annealing treatments in this material. The present results would seem to leave little room for optimism concerning this approach. Significant drawability was only achieved at temperatures much higher than those at which the rolling texture could be retained. Insufficient recovery, and hence ductility, are associated with the low-temperature, long-time annealing route thereby mitigating against exploitation of the retained rolling texture in enhancing drawability.

Perhaps a more tractable approach is to be found in the use of material less severely cold rolled prior to annealing. Moderate amounts of cold rolling would provide a reduced driving force for recrystallization, allowing recovery to occur while preserving the rolling texture. The resulting retained rolling texture, albeit weak, might be intensified by several consecutive cycles of moderate rolling followed by low temperature recovery treatments. Indeed, it has recently been reported that in commercial non-earing 70/30 brass cold rolled 40% to 50%, the main texture present after annealing is a weak {110}<112> texture even in the fully recrystallized condition.[14]

Similarly, the use of short-time, high-temperature annealing treatments following severe cold rolling of 70/30 brass does not appear to offer advantages in terms of the production of textures favorable for drawing at a reasonable grain size. An annealing time of only 10 s at 750°C (1023°K) limits the grain size to ∿50 μm, but results in material for which the texture and drawability are substantially the same as that produced by annealing at lower temperatures for longer times to achieve a similar grain size. The texture in both cases is the primary recrystallization texture characteristic of brass initially cold-rolled >90% reduction, i.e. {113}<112>. It is only by allowing grain growth to occur at the higher temperatures that {110}<112> is produced as a secondary texture.

SUMMARY

In heavily cold-rolled α-brass, {110} textural components can only be produced by a) very low temperature annealing treatments which, while partially retaining the rolling texture, result in a recovered but hard, incompletely recrystallized condition of low drawability; or b) by promoting extreme grain growth subsequent to recrystallization which renders the material unsuitable for many commercial drawing applications.

ACKNOWLEDGMENTS

This study was supported by the International Copper Research Association, New York, N. Y. 10022. The authors wish to thank Jack Crane and Eugene Shapiro (Olin Corporation; Brass Group) for provision of materials and for their interest in the work.

REFERENCES

1. W. A. Backofen, W. F. Hosford, Jr., and J. J. Burke, *ASM Trans. Quart.*, 55, 264 (1962).
2. W. F. Hosford, Jr. and W. A. Backofen, in *Fundamentals of Deformation Processing*, J. J. Burke, V. Weiss, L. F. Coffin, Jr., N. L. Reed, and W. A. Backofen, eds., Syracuse University Press, Syracuse, 1964, p. 259.
3. W. F. Hosford, *Metals Eng. Quart.*, 6, 13 (1966).
4. D. V. Wilson, *J. Inst. Metals*, 94, 84 (1966).
5. W. T. Roberts, *Sheet Metal Industries*, 43, 237 (1966).
6. D. V. Wilson, *Met. Revs.*, No. 139, 175 (1969).
7. F. H. Wilson and R. M. Brick, *Trans. AIME*, 161, 173 (1945).
8. H. Hu, R. P. Sperry and P. A. Beck, *Trans. AIME*, 194, 76 (1952).
9. A. Merlini and P. A. Beck, *Trans. AIME*, 203, 385 (1955).
10. P. A. Beck and H. Hu, *Trans. AIME*, 194, 83 (1952).
11. S. Horiuchi, T. Okubo, and I. Gokyu, *Trans. Japan Inst. Metals*, 8, 153 (1967).
12. S. R. Goodman and H. Hu, *Trans. TMS-AIME*, 242, 88 (1968).
13. K. Lücke and U. Schmidt, *J. Less Common Metals*, 28, 187 (1972).
14. F. E. Schmidt, Jr. and A. Lawley, *Metals Eng. Quart.*, 13, No. 3, 1 (1973).
15. L. G. Schulz, *J. Appl. Phys.*, 20, 1030 (1949).
16. L. R. Hawtin, *Sheet Metal Industries*, 46, 418 (1969).

17. D. V. Wilson, B. J. Sunter, and D. F. Martin, *Sheet Metal Industries*, 43, 465 (1966).
18. B. J. Sunter, *J. Austr. Inst. Metals*, 12, 166 (1967).
19. M. Atkinson, *J. Iron and Steel Inst.*, 208, 58 (1970).
20. I. Gokyu, K. Suzuki, and C. Fujikura, *Trans. Japan Inst. Metals*, 12, 268 (1971).
21. E. Shapiro and J. Crane, private communication, Olin Corporation, Brass Group.